92-235

# GEC-Marconi
Communications

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MAY 27 1993

FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY


24 May 1993

Office of the Secretary,
Federal Communications Commission,
Washington
D.C. 20554
USA

Dear Sir,

We thank you for the opportunity to comment on the Notice of proposed Rule Making on more efficient use of spectrum below 512 MHz.

GEC-Marconi is an established Company in the UK, manufacturing, among many things, Land Mobile Radio Equipment for the U.K. market. We also have Companies who operate in the U.S.A.

We do not have Land Mobile Radio products currently on sale in the U.S.A., so we have directed our comments towards making the most flexible, efficient use of narrowband technology, which is of relevance to our work in the APCO Project 25 group, where we play a significant role in the Standard making activity.

Our paper analyses the parameters that affect modulation schemes for spectrum efficient communications. These include:

* Frequency stability
* Power amplifier linearity
* Doppler shifts
* Filter roll-off
* Emission mask
* Codec
* Modulation method


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We show that the technical difficulties that exist at present are being solved, and that narrowband channel working will be available in the next two to three years. As a result we question the two stage migration to narrowband, and suggest that a single stage, especially for those users who want to move to narrowband, should be considered. Technically the use of 5 kHz at VHF and 6.25 kHz at UHF is an unnecessary complication. A single objective of 6.25 kHz would be preferable.

We include a table giving an example of how an evolutionary path which is both open and flexible can be followed. It is important that the Rules do not stifle technology developments such as multi-level QAM and low bit-rate voice codecs. It should be possible to stack channels if higher data rates are needed, and the user is able to demonstrate the need for the appropriate amount of spectrum. We believe that technologies should be compared on the basis of efficiency.

It is important that the FCC develops Rules that protect users from interference, while being open and flexible so that technology can move forward. We are very interested in the outcome of the FCC proposals on making more efficient use of spectrum, and will assist in any way.

Yours sincerely,

**DR. S. ROTHERAM**
**Technical Director**

Enc.

92235

GEC-MARCONI COMMUNICATIONS LIMITED

27 April, 1993

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

# PRIVATE LAND MOBILE RADIO

# MIGRATION TO NARROWBAND CHANNELS

## 1. INTRODUCTION

The need to increase spectrum efficiency, together with the emergence of new digital transmission and implementation technologies, provides the opportunity for the land mobile radio industry and users to make a big step forward. The FCC Docket 92-235

## 2. FACTORS AFFECTING MIGRATION TO NARROW CHANNELS

### 2.1 Access Method

The access method can be FDMA, TDMA or CDMA or mixtures thereof. FDMA is the simplest in terms of implementation and ease of migration which can be on a channel-by-channel basis. This is important for users with single channel systems for which TDMA and CDMA provide overkill. Many such users are in relatively low population density areas for which migration itself may be unnecessary because spectrum usage is low. The FCC should consider whether migration should be mandated on a national basis or on a regional basis for high usage areas. This consideration also applies to the proposed restrictions on antenna height and power. Migration in low usage areas could be optional and only become mandatory on longer time scale. Users can still migrate to narrowband equipment whilst keeping wider channel assignments.

TDMA offers advantages over FDMA in terms of frequency re-use due to lower interference levels. It is therefore better suited to high usage areas. The intrinsic multi-channel nature of the method makes it suited to trunked operation.

CDMA offers further advantages in frequency re-use but requires at least 1 MHz of contiguous spectrum. Consideration should be given to licensing CDMA overlays for secure applications requiring a Low Probability of Intercept (LPI) capability.

### 2.2 Spectrum Efficiency

The narrower the channel, the less capacity there is to transmit the data stream, unless higher level modulation schemes are used. Table 1 shows the efficiency in bits/second/Hz for a number of current and proposed systems, all of which use a 4-level modulation scheme.

**Table 1**

| System | Modulation | Bandwidth (kHz) | Bit Rate (kbps) | Efficiency bits/s/Hz |
|---|---|---|---|---|
| D-AMPS | $\pi/4$-DQPSK | 30 | 48 | 1.6 |
| TETRA | $\pi/4$-DQPSK | 25 | 36 | 1.44 |
| APCO 25 | QPSK-C | 12.5 | 9.6 | 0.77 |
| APCO 25 | QPSK-C | 6.25 | 9.6 | 1.54 |

On this basis the proposed APCO 25 standard at 12.5 kHz with an efficiency of 0.77 bits/s/Hz is an inefficient use of spectrum. By the same token the proposed APCO 25 migration to 9.6 kbps in 6.25 with efficiency of 1.54 bits/s/Hz looks achievable by comparison with D-AMPS and TETRA. However these are 25 or 30 kHz systems where the occupied channel bandwidth as a proportion of the channel spacing is greater. This is because the tolerances required for frequency stability, Doppler and implementation errors are largely independent of channel spacing. The proposed FCC occupied bandwidth for 6.25 kHz channels is 5 kHz for which the proposed APCO 25 9.6 kbps would require an efficiency of 1.92 bit/s/Hz which is not achievable with 4-level modulation. The best that can be achieved in 5 kHz is 8 kbps, an efficiency of 1.6 bits/s/Hz.

The use of higher level modulation schemes such as 8PSK and 16 QAM will allow efficiencies in occupied bandwidths of about 2.4 and 3.2 bits/s/Hz respectively, but with a trade off in equipment complexity.

## 2.3 Doppler

Since the mobile unit will move, this has to be taken into account. There will be two Doppler shifts for mobile to mobile calls (where for instance two cars are heading towards each other on a highway). There may be two shifts for mobile to repeater calls, since an interferer could be heading away from a repeater station while the wanted signal could be heading towards the repeater station. For vehicles travelling at 75 mph, Doppler shifts of 45, 100 and 190 Hz must be accommodated at 200, 500 and 860 MHz respectively.

## 2.4 Frequency Stability

This will concern both the repeater station and the mobile unit. Present stabilities

The repeater station stability may be solved by fitting a stable oscillator, say 0.1 ppm. The additional power consumption and size of an oven controlled reference is acceptable.

On the other hand it is not practical to fit such devices into a mobile or especially a handheld. Digitally compensated oscillators with a stability of 0.2 ppm are becoming available, but at present the cost is very high. The device is based on an ASIC, and costs will gradually reduce with time. An alternative is to use the repeater transmitter to derive a stable mobile unit reference, using clock recovery from the received carrier. This is possible, but is more difficult with the non-constant carrier envelope. This will operate while the mobile unit is seeing the repeater station, but a requirement of APCO is mobile to mobile communications (Talkaround).

Once the mobile loses contact with the repeater station the oscillator will be free running, and stability becomes critical. In particular the oscillator will be affected by short term temperature variations, and the receiver may not be able to lock to the transmitter.

Figure 1 shows the required frequency margin against frequency for a range of oscillator stabilities from 0.1 to 1.5 ppm, but also including the Doppler shifts given in Section 2.3. Also shown in Figure 1 are the frequency margins of 1.25/1 khz for the FCC 6.25/5 kHz channel spacings with 5/4 kHz occupied bandwidths. Finally, there is shown the frequency margin of 490 Hz for the current APCO 25 proposal of 9.6 kbps in 6.25 kHz with an occupied bandwidth of 5.76 kHz.

## 2.5 Modulation Methods

Constant envelope schemes such as FM have traditionally been used in land mobile radio together with efficient Class C power amplifiers. The APCO 25 standard proposes the use of C4FM at 12.5 kHz as a digital equivalent. Such methods suffer from the drawback of poor spectral efficiency though methods such as Continuous Phase Modulation (CPM) go some way to mitigate this deficiency.

The trend in modern communications is to move to digital modulation schemes such as QAM or PSK. A number of current systems (see section 2.2) use $\pi/4$-DQPSK (a form of QAM) which is simple to modulate and demodulate and by avoiding the zero crossing point is less demanding on the power amplifier. These schemes, however, require linear power amplifiers as discussed in Section 2.6.

As a compatible alternative to C4FM, APCO 25 has proposed the use of CQPSK, a variant of QPSK in which all of the filtering is at the transmitter, as a linear modulation. This scheme has a 1.5 dB degradation compared with $\pi/4$-DQPSK.

A number of papers (Ref: 1) have pointed to the use of higher level QAM schemes such as 16QAM in future mobile systems. This allows a doubling of bit-rate, or a halving of occupied bandwidth as compared with QPSK.

There is a trade-off in that 16QAM requires about 6 dB greater signal to noise (S/N) or carrier to interference (C/I) ratios. The higher S/N can be mitigated by using higher transmit powers but the higher C/I required means that for an interference limited system the gain in spectral efficiency measured in bits/s/Hz is almost exactly set off by an increase in re-use factors. However there may still be advantages in higher level QAM; the increased bit rate can be used for special services such as high bit rate data, and many systems may not be limited by interference. Square QAM constellations have traditionally been used in modern communication systems, but analysis has shown that star QAM is superior for Rayleigh fading channels (Ref: 1). Multi level schemes also require coherent demodulation, adding to the complexity of the receiver though this will become practical for handportable radios in the next few years.

SSB has been proposed for narrowband applications including the addition of pilot tones to provide amplitude and frequency correction. The Transparent-Tone-In-Band (TTIB) technique developed at Bristol University in the UK offers many advantages (Ref: 2). However the gains in spectrum efficiency may be illusory. As shown in Reference 3, SSB requires much larger re-use factors than FM by a factor of order 6 so that SSB channels must be six times narrower than equivalent FM channels. Using voice band modems digital speech or data can be passed through the linear SSB channel. For example 16QAM modems have been used to pass 9.6 kbps through a 5 kHz channel. One may question the wisdom of using a 16QAM modem to pass data through an SSB channel rather than using 16QAM directly; but we have not compared these directly as yet.

## 2.6 Power Amplifier Linearity

Any efficient modulation scheme is going to require a linear power amplifier for the transmitter. The modulation generates an amplitude characteristic which must be preserved, and the choice of scheme and filtering determines how linear the amplifier needs to be.

Work is being done in industry and universities on various types of linear power amplifier; three possible techniques being Cartesian loop, pre-distortion or the LINC transmitter. Breadboarded designs meet a -60 dB adjacent channel power requirement and -70 dB looks to be achievable in the near future. Power amplifiers have already been demonstrated with an adjacent channel power of -64 dB and power efficiencies of 55 to 65%, using $\pi/4$-DQPSK filtered with an $\alpha$ of 0.2. Hence the power amplifier is not regarded as a problem and production versions will be available in the next two years.

## 2.7 Filter roll-off

Root raised cosine filtering is the commonest approach with the filter roll-off value $\alpha$ in the range 0.2 to 0.5. Lower values give narrower occupied bandwidths but longer filters and greater complexity which is why $\alpha=0.2$ is the lowest practical value. An important formula linking bit rate, occupied bandwidth and filter roll-off value $\alpha$ is:

$$\text{Occupied bandwidth} = \frac{\text{bit-rate} * (1+\alpha)}{n}$$

where n is the number of bits per symbol e.g. n=2 for QPSK, n=4 for 16QAM.

Another important consideration is that reducing $\alpha$ increases the peak to mean of the transmitted signal. For $\alpha=0.35$ this is about 3 dB whereas for $\alpha=0.2$ it is 5 dB. Assuming that the power amplifier at peak output is at the same point on its output characteristic, this means that the mean must be backed-off by 2 dB more for $\alpha=0.2$ as compared with $\alpha=0.35$. This means that the power amplifier must be rated 2 dB higher in its mean power giving extra cost in the implementation.

## 2.8 Spectrum Mask

Figures 4 and 5 show the proposed FCC masks for 5 and 6.25 kHz channels. Essentially the occupied bandwidth is confined to 4 and 5 kHz, providing margins of 1 and 1.25 kHz. We would propose that when two such channels, or an equivalent 2 channel TDMA system, are stacked in a 10 or 12.5 kHz channel, the margins should be the same giving occupied bandwidths of 9 and 11.25 kHz.

## 2.9 Maximum bit-rate

The maximum bit rate that can be supported within a given occupied bandwidth is given in Section 2.7. Figures 2 and 3 provide a graphical representation of this formula.

Figure 2 shows curves for the three modulation types with $\alpha = 0.2$ and 0.35. Also shown are horizontal dashed lines corresponding to the proposed FCC 6.25 or 5 kHz emission masks with occupied bandwidths of 5 or 4 kHz respectively. The vertical dashed line shows the APCO proposed bit rate of 9.6 kbps. This diagram allows one to tell at a glance what combinations of bit-rate, occupied bandwidth (emission mask), modulation type and filter roll off are feasible. For example, the FCC 6.25 kHz mask with the APCO 9.6 kbps bit-rate cannot be achieved with any practical form of QPSK.

Figure 3 is the same as figure 2 but extended to cover 2 channel TDMA systems. We have marked on this figure horizontal lines for 12.5 kHz and 10 kHz channels where we have assumed occupied bandwidths of 11.25 and 9 kHz, i.e. the same frequency margin as for the 6.25 and 5 kHz FCC masks. We have also shown a vertical line at 19.2 kbps which is twice the APCO proposed bit rate of 9.6 kbps.

## 2.10 Voice codec

APCO 25 has selected the IMBE codec at 4.4 kbps with 2.8 kbps of protection giving a protected bit-rate of 7.2 kbps. The IMBE codec has also been chosen for Inmarsat Standard M at a protected rate of 6.4 kbps. There appears to be little difference in speech quality. Waveform codecs such as IMBE have the attractive property of graceful degradation as the bit-rate is reduced, thus offering the promise of even lower bit-rate codecs in the future. An IMBE codec at 3.2 kbps with 1.6 kbps of protection giving an overall rate of 4.8 kbps has been demonstrated to be only marginally inferior to the APCO 7.2 kbps codec. Below this rate the quality degrades rapidly.

## 2.11 Digital Implementation

Modern radios are increasingly being implemented digitally in that at some point in the receiver or transmitter chain there is an analogue-to-digital convertor (ADC) or digital-to-analogue convertor (DAC) following or preceding which all processing os carried out digitally. Three architectures have been proposed, namely, direct conversion, heterodyne with baseband ADC and heterodyne with bandpass ADC.

## 2.12 Implementation Complexity

Modern digital signal processors, or equivalent ASICs, operate at typical rates of 33 or 50 MHz. This means that a radio with 2 or 3 such devices can easily deliver 100 MIPS of processing power. For example the European GSM digital cellular system requires about 80 MIPS. Digital land mobile systems envisaged such as APCO 25 and TETRA will require 50 to 100 MIPS which is within current capabilities. It is envisaged that the processing power available in a handportable radio will double every two years for the foreseeable future, reaching 1000 MIPS by the year 2000. These figures should be borne in mind in considering how complex future migrations will be. The radio of the year 2000 will be very smart!

## 2.13 Flexibility

We would like to emphasize the need for migration paths to be flexible. Future radios will be very smart and support a number of modes. There is a need for backward compatibility with analogue FM and interoperability with other systems. There is a need for voice and data modes and, in the future, video. As shown in section 6, radios can offer alternative bit-rates, modulations and bandwidths to suit different applications. To facilitate this we like the concept of stacking whereby a user may use a 12.5 kHz channel to support two 6.25 kHz FDMA channels, a two slot TDMA channel or one high bit-rate 12.5 kHz FDMA channel, providing the margins and emission masks at the edge of the band are the same. We would like to emphasize the need for migration paths to be open so as to permit evolution as lower bit-rate vocoders and higher level modulation methods become available. The rules should be generic and not specific to one particular scheme.

## 3. APCO PROJECT 25

GEC-Marconi is actively supporting the development of the APCO Project 25 standard, including chairing the System Task Group. Initially APCO 25 is developing a 12.5 kHZ standard which has the following characteristics:-

- 9.6 kbps bit-rate
- IMBE vocoder at a protected bit-rate of 7.2 kbps
- C4FM or CQPSK modulation.

Whilst this forms a viable interim standard, GEC-Marconi have some misgivings about the standard:

- C4FM does not fit in the standard 12.5 kHz Part 90 mask
- The modulation method is patented
- CQPSK has inferior performance to $\pi/4$-DQPSK giving a 1.5 dB degradation and a 20% reduction in coverage.

The CQPSK modulation was originally intended as the migration option to 6.25 kHz channels. However 9.6 kbps with $\alpha = 0.2$ occupies 5.76 kHz and will not fit in the proposed FCC Part 88 mask as shown in figure 4.

For these reasons we believe the current path being pursued by Project 25 is fundamentally flawed. The fundamental flaw in the migration to 6.25 kHz is the bit-rate; a maximum of 8 kbps can be supported in the 6.25 kHz channel with four level modulation.

Another flaw in the current proposals is that they form a technological dead-end. There is no obvious migration to 6.25 kHz and no further step envisaged in the future.

## 4. TETRA

In parallel with APCO 25, a digital land mobile radio standard is being developed in Europe. This is TETRA ( **T**rans **E**uropean **T**runked **Ra**dio). It will be a family of standards as follows:

a. A voice and data standard with 25 kHz channels, 36 kbps bit-rate and $\pi/4$-DQPSK modulation using 4 slot TDMA access
b. A data only standard similar to (a)
c. A direct mode (talkaround)
d. A voice and data standard with 12.5 kHz channels, 18 kbps bit-rate using 2 slot TDMA access.

A phase 1 standard for item (a) will be completed towards the end of 1993. A phase 2 standard for the other items will be completed by the middle of 1994. TETRA products are expected to appear in 1995.

## 5. SUMMARY OF MIGRATION PATHS

In table 2 we have summarized a number of migration options covering FDMA and TDMA access, various bit-rates, $\alpha$ values and modulation methods. The columns in the table are explained as follows:

| Column | Description |
|---|---|
| 1 | Bit-rate, channel spacing and access method |
| 2 | Split between the vocoder(protected) and overheads |
| 3 | Modulation type |
| 4 | Filter Roll-off value $\alpha$ |
| 5 | Degree of compatibility with the APCO 12.5 kHz proposed standard. CQPSK has a compatible receiver. Other options are compatible with the 7.2 kbps vocoder, the 2.4 kbps overhead, or neither. |
| 6 | Occupied bandwidth as in figures 2 and 3 |
| 7 | Whether the option can meet the FCC Part 88 proposals |
| 8 | Required frequency stability at 200, 500 and 860 MHz as in figure 1 |
| 9 | The linearity requirements as in the explanatory notes |
| 10 | Further observations. |

# 6. MARCONI PROPOSAL

In table 3, in the same format as table 2, we have set out a family of highly compatible standards which we believe meets all requirements. The first part of the table covers FDMA options and the second part TDMA options.

The proposals have the following features:-

(a) The baseline (and simplest option) is FDMA access in 6.25 kHz channels with 8 kbps data rate and $\pi$/4-DQPSK modulation. Voice coding is the IMBE codec at 6.4 kbps with 1.6 kbps of overheads. This fits inside the proposed FCC 6.25 kHz emission mask.

(b) Two such channels can be stacked in one 12.5 kHz channel (or four in 25 kHz).

(c) A high bit-rate option is one FDMA channel in 12.5 kHz with 16 kbps data rate and $\pi$/4-DQPSK. High quality voice or high speed data at 12.8 kbps can be supported, with 3.2 kbps of overheads.

(d) If only 6.25 kHz channels are available to the user only the baseline option (a) is implemented.

(e) Providing 12.5 kHz channels are available and stacking is allowed, options (a) and (c) can be supported in the same system with the baseline option (a) used on the control channel but either option on traffic channels.

(f) A future migration to 16QAM with half the occupied bandwidths of options (a) and (c) is envisaged. 3.125 kHz channels can be stacked in 6.25 or 12.5 kHz channels. 16 QAM modulators and demodulators can also support $\pi$/4-DQPSK, a form of 4QAM, using coherent Viterbi decoding and so the same radio can support all of these FDMA modes. The baseline mode can be used on the control channel with any of the other modes called up as required as traffic channels. This migration will support 8 kbps, 16 kbps and 32 kbps modes in 3.125, 6.25 and 12.5 kHz channels.

(g) The baseline TDMA mode is two slot TDMA in 12.5 kHz with 16 kbps overall bit-rate, $\pi$/4-DQPSK, IMBE vocoder at 6.4 kbps and 1.6 kbps overhead per user. The other TDMA options envisage a migration to 16QAM with similar options

## 7. RECOMMENDATIONS

Based on the preceding analysis GEC-Marconi recommends the following:-

(a) A two-step migration through 12.5 kHz channels will not achieve significant improvement in the first step as many existing 25 kHz channels have 12.5 kHz offsets with geographical separation.

(b) The short-term (two years) availability of 6.25 kHz technology means that a one-step migration should be considered.

(c) The transition to 6.25 kHz channels at UHF and 5 kHz channels at VHF is an unnecessary complication. If possible a single objective of 6.25 kHz, or equivalent efficiency in 12.5 kHz, should be pursued.

(d) The migration path can be made flexible, and driven by market demand, by moving to exclusive use 12.5 kHz channels in which the user can implement a number of alternatives as described in Section 6.

(e) The migration path should be open and flexible to allow for technological developments such as multi-level QAM (Section 2.5) and low bit-rate voice codecs (Section 2.10).

(f) We support the proposed mask for 6.25 kHz channels with 5 kHz occupied bandwidth. The same margin at the edge of stacked 12.5 kHz channels should be allowed, that is, an occupied bandwidth of 11.25 kHz.

(g) Technologies should be mandated on the basis of efficiency. A minimum efficiency of 1.28 bits/s/Hz (equivalent to 8 kbps in 6.25 kHz) should be the long term objective.

(h) Re-use efficiency should also be considered though there is no widespread agreement on appropriate re-use values. On this basis SSB is suspect (see Section 2.5).

# References


[1] W.T. Webb, 'QAM, The modulation scheme for future mobile radio communications?', IEE Electronics and Communications J., Vol. 4, No. 4, Aug. 1992, pp 1167 - 1176.

[2] J.P. McGeehan and A.J. Bateman, 'Phase-locked transparent tone-in-band (TTIB): A new spectrum configuration particulurly suited to the transmission of data over SSB mobile radio networks', IEEE Trans. on Communs., Vol. Com-32, No. 1, Jan 1984, pp 81 - 87.

[3] V.K. Prabhu and R. Steele, 'Frequency hopped single sideband modulation for mobile radio', BSTJ, Vol. 61, No. 7, Part I, Sept. 1992, pp 1389 - 1411.

TABLE 2

## Narrowband Migration Options

| OPTION | | Occupied B/width kHz. | | Frequency Stability (ppm) See note 2 | | |
|---|---|---|---|---|---|---|

TABLE 2 Cont.

| OPTION | | | | | Occupied B/width kHz. | | Frequency Stability (ppm) See note 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bit Rate/ Channel spacing | Vocoder/ O/head kbps | Mod. | Filter ($\alpha$) | Compatibility with 12.5kHz | See Note 1 | Part 88 | 200 MHz | 500 MHz | 860 MHz | Linear amplifier | Remarks |
| 19.2kbps 12.5 kHz 2Ch-TDMA | 7.2<br>2.4 | $\pi$/4-DQPSK | 0.2 | Codec O/H | 11.52 | No | 2.3 | 0.88 | 0.46 | Note 3 | The use of TDMA makes the stability better, even for 2 * 9.6kb. |
| 17.6kbps 12.5 kHz 2Ch-TDMA | 6.4<br>2.4 | $\pi$/4-DQPSK | 0.3 | O/H | 11.44 | No | 2.5 | 0.96 | 0.5 | Note 4 | The power amp linearity is less onerous than 19.2 kbps. |
| 17.6kbps 12.5 kHz 2Ch-TDMA | 6.4<br>2.4 | $\pi$/4-DQPSK | 0.2 | O/H | 10.56 | Yes | 4.7 | 1.8 | 1.0 | Note 3 | |
| 36 kbps 25 kHz TETRA 4Ch-TDMA | 7.2 | $\pi$/4- DQPSK | 0.35 | Not Known | 24.3 | No | 1.6 | 0.6 | 0.3 | Note 3 | Codec not chosen. |
| 18 kbps 12.5 kHz TETRA 2Ch-TDMA | 7.2 | $\pi$/4-DQPSK | 0.35 | Not Known | 12.15 | No | 0.76 | 0.25 | 0.09 | Note 3 | Codec not chosen. |
| 9.6 kbps TTIB-SSB | 7.2<br>2.4 | 16 QAM sub-carrier | n/a | Codec O/H | | Yes | | | | Note 5 | The use of TTIB allows high data rates to be sent, but using modems and sub carrier modulation. |

TABLE 3

*Marconi Proposal - FDMA Options*

| OPTION | | | | | | | Frequency Stability | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bit Rate/ Channel spacing | Vocoder/ O/head kbps | Mod. | Filter ($\alpha$) | Compatibility with 12.5kHz | Occup.d B/width kHz. | Part 88 | 200 MHz | 500 MHz | 860 MHz | Linear amplifier | Remarks |

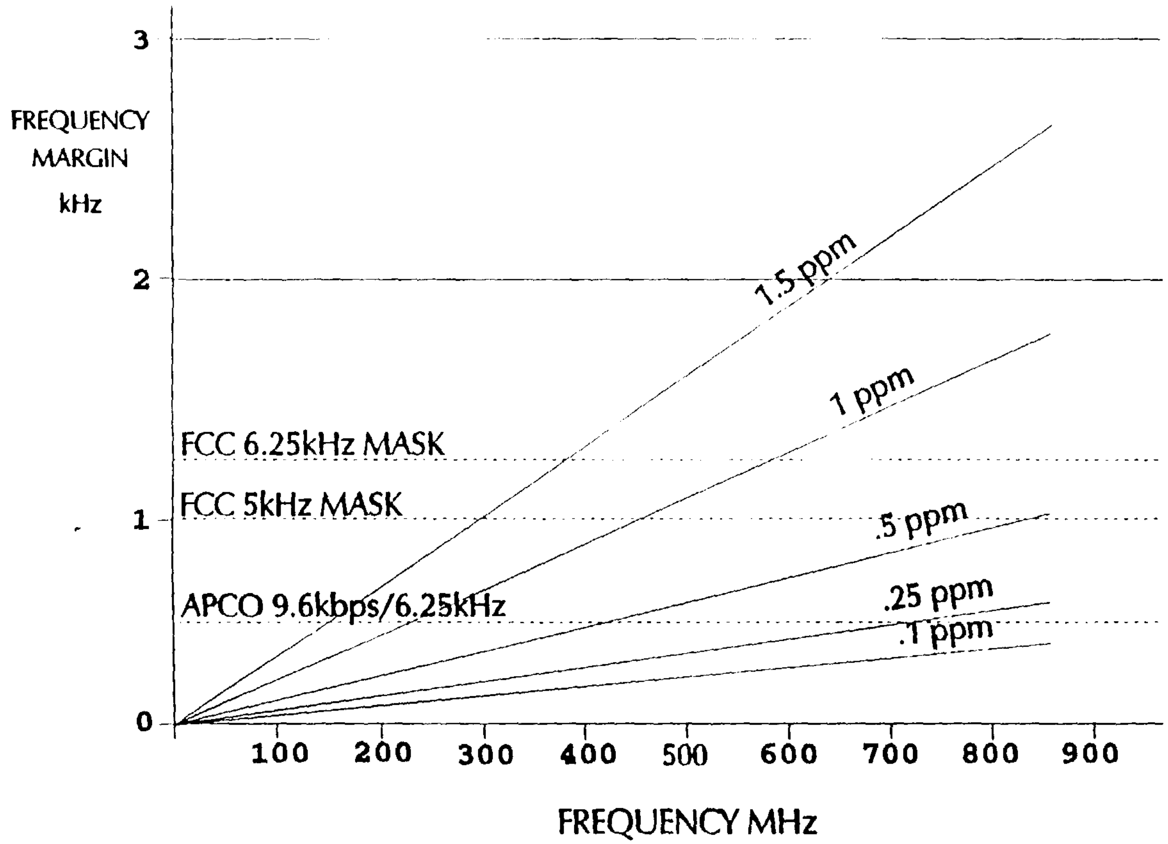
TABLE 3 Cont.

*Marconi Proposal - TDMA Options*

| OPTION | | | | | | | Frequency Stability | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bit Rate/ Channel spacing | Vocoder/ O/head kbps | Mod. | Filter (α) | Compatibility with 12.5kHz | Occupied B/width kHz. | Part 88 | 200 MHz | 500 MHz | 860 MHz | Linear amplifier | Remarks |
| 16 kbps 12.5 kHz 2 Ch-TDMA | 6.4 1.6 | π4-DQPSK | 0.2 | No | 9.6 | Yes | 7.1 | 2.8 | 1.6 | Note 3 | No problem with stability. Direct mode problem. Similar to TETRA. |
| 16 kbps 6.25 kHz 2 Ch-TDMA | 6.4 1.6 | 16 QAM | 0.2 | No | 4.8 | Yes | 3.5 | 1.35 | 0.73 | Note 5 | No problem with stability. Future migration. |
| 32 kbps 12.5 kHz 2 Ch-TDMA | 12.8 3.2 | 16 QAM | 0.2 | No | 9.6 | Yes | 7.1 | 2.8 | 1.6 | Note 5 | No problem with stability. Future migration. High quality voice. High speed data. |
| 32 kbps 12.5 kHz 4 Ch-TDMA | 6.4 1.6 | 16 QAM | 0.2 | No | 9.6 | Yes | 7.1 | 2.8 | 1.6 | Note 5 | No problem with stability. Future migration |

Note 1: Occupied bandwidth is derived by the formula:

Occupied bandwidth = Bit rate * (1 + $\alpha$) where N is 2 for QPSK and $\pi/4$ DQPSK



3
FREQUENCY
MARGIN
kHz
2
1.5 ppm
1 ppm
FCC 6.25kHz MASK
FCC 5kHz MASK
1
.5 ppm
APCO 9.6kbps/6.25kHz
.25 ppm
.1 ppm
0
100
200
300
400
500
600
700
800
900
FREQUENCY MHz


FIGURE 1

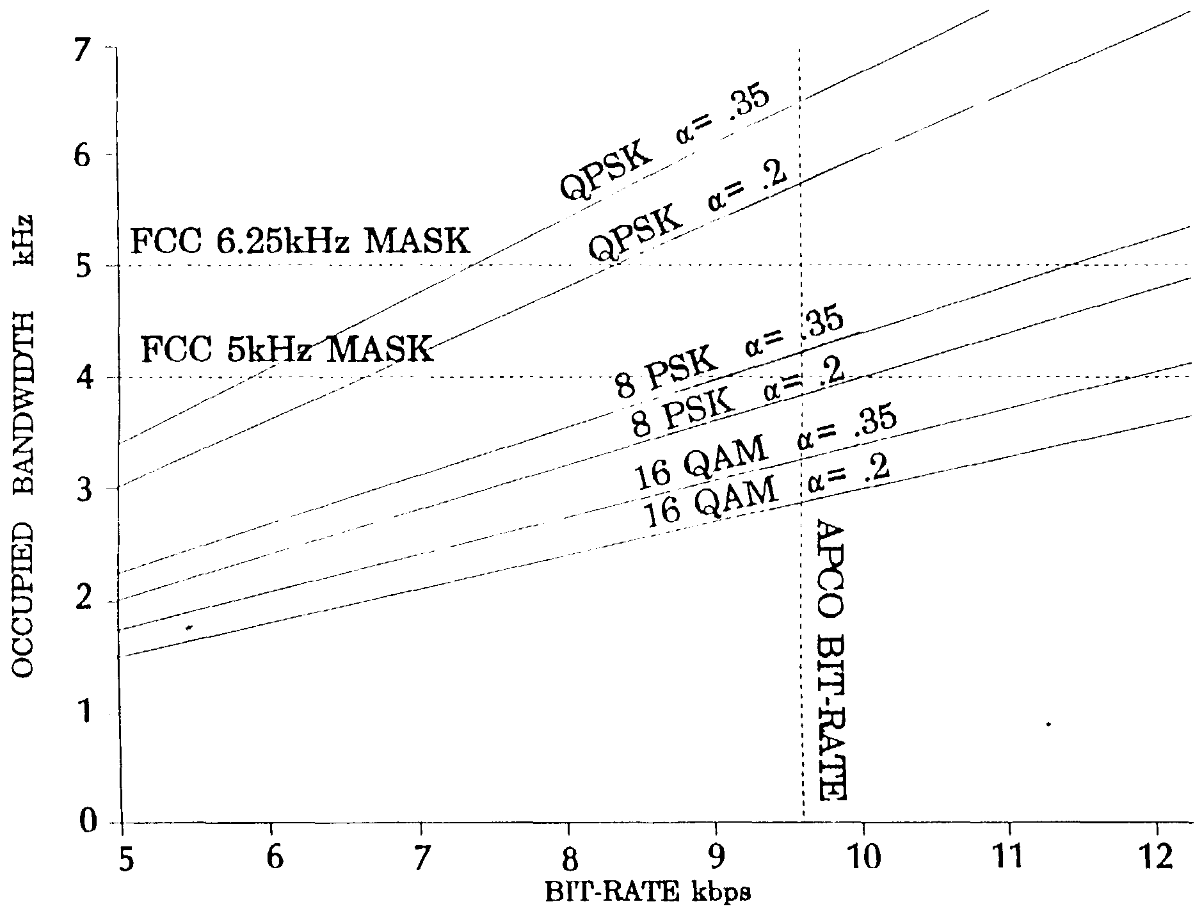

OCCUPIED BANDWIDTH kHz
0
1
2
3
4
5
6
7
FCC 6.25kHz MASK
FCC 5kHz MASK
QPSK α= .35
QPSK α= .2
8 PSK α= .35
8 PSK α= .2
16 QAM α= .35
16 QAM α= .2
APCO BIT-RATE
5
6
7
8
9
10
11
12
BIT-RATE kbps

FIGURE 2

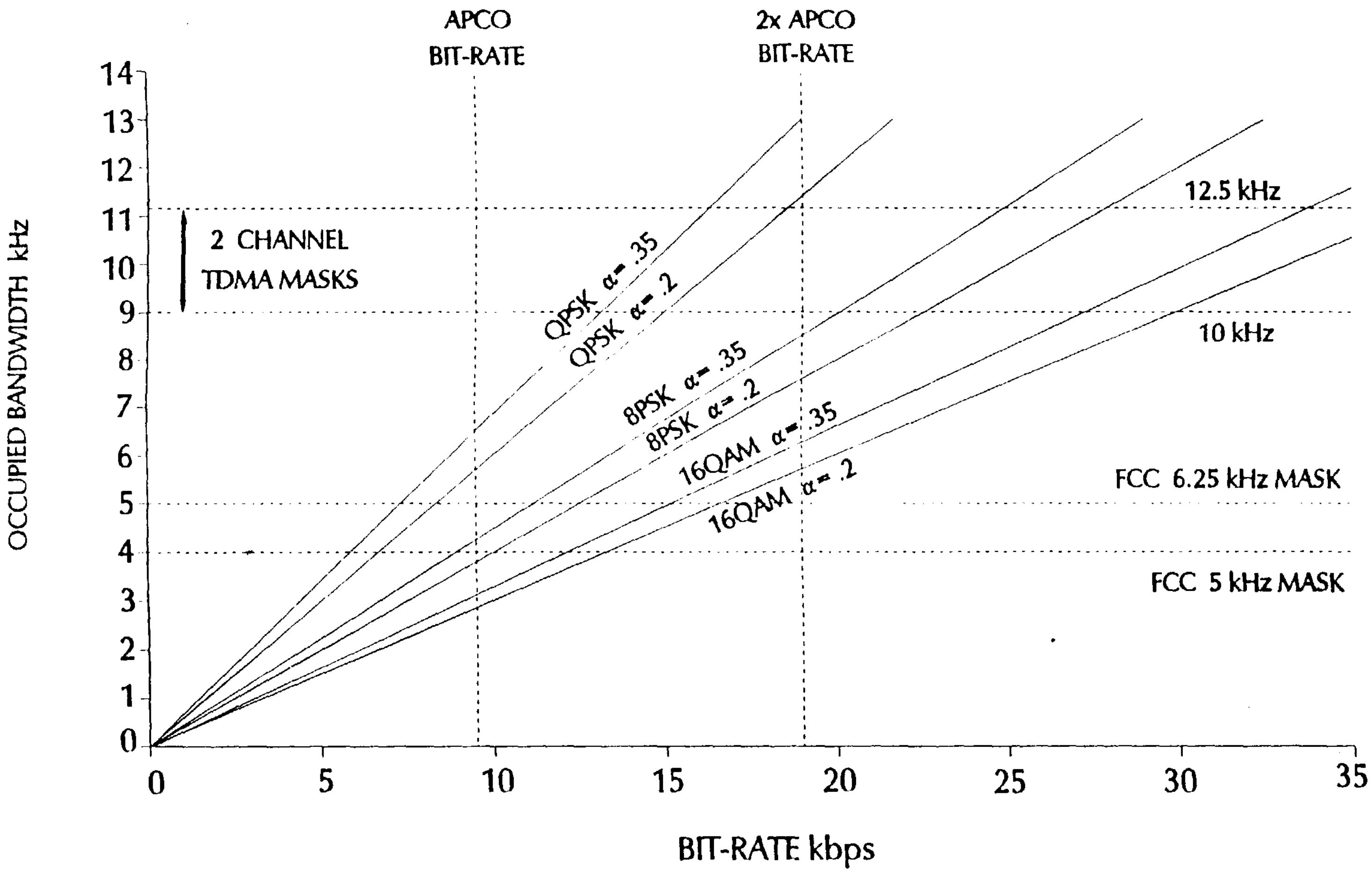

APCO
BIT-RATE
2x APCO
BIT-RATE
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
OCCUPIED BANDWIDTH kHz
2 CHANNEL
TDMA MASKS
QPSK α= .35
QPSK α= .2
8PSK α= .35
8PSK α= .2
16QAM α= .35
16QAM α= .2
12.5 kHz
10 kHz
FCC 6.25 kHz MASK
FCC 5 kHz MASK
0
5
10
15
20
25
30
35
BIT-RATE kbps

FIGURE 3